establishing a series of different centrally related perimeter limits of area-scan action within the perimeter of said central area and for coordinating the operation of said scan-deflection means in a controlled program of limitation of one area scan within one perimeter limit before repeating such coordination within the next-successive perimeter limit in the series, whereby ablative penetration to said maximum depth is the cumulative result of plural area scans of each of a succession of different but overlapping areas.

9 ~~30.~~ Apparatus according to claim ~~29~~ 8, further comprising eye-fixation means fixed with respect to said chassis and aligned for observation through the other eye of the patient.

D/ Cont'd.

10 ~~31.~~ Apparatus according to claim ~~29~~ 8, wherein said laser means is an excimer laser operative with a gas selected from the group comprising fluorine, argon fluoride, krypton fluoride, xenon chloride, and xenon fluoride.

11 ~~32.~~ Apparatus according to claim ~~29~~ 8, wherein said laser means produces an output beam characterized by a wavelength not substantially exceeding 400 nm.

12 ~~33.~~ Apparatus according to claim ~~29~~ 8, in which said scan-deflection means comprises mechanically displaceable optical components, and means for displacing said optical components to effect a predetermined deflection of said beam.

13 ~~34.~~ Apparatus according to claim ~~29~~ 8, in which said laser means includes a means for reducing said beam cross-section at the eye of the patient to a spot size in the range of 30 microns to 0.5mm.

14 ~~35.~~ Apparatus according to claim ~~29~~ 8, in which said means for steadying the cornea includes a circumferentially continuous hollow annular ring which is air-permeable at one axial side, said side being contoured for adaptation to the corneal scleral region of an eye, and an external-connection port to the hollow of said ring for external air-evacuating connection of the same.

15 8
~~36.~~ Apparatus according to claim ~~29~~, in which said scan-deflection means is radially operative with respect to the axis of said beam at incidence with the cornea, said scan-deflection means including further means for rotating the direction in which the radial deflection is operative.

16 15
~~37.~~ Apparatus according to claim ~~36~~, in which said further means is continuously operative in the course of a given radial-scan operation, whereby each area scan is the result of a spirally developed course of beam deflection.

17 8
~~38.~~ Apparatus according to claim ~~29~~, in which said perimeter limits are circular outer limits of successive different concentrically related scanned areas, whereby the cumulative result of microprocessor control of successive-area scanning of the cornea is myopia-correcting.

D1 Cont'd

18 8
~~39.~~ Apparatus according to claim ~~29~~, in which said perimeter limits are circular inner limits of successive different concentrically related scanned annular areas of constant outer diameter, whereby the cumulative result of microprocessor control of successive-area scanning of the cornea is hyperopia-correcting.

19 8
~~40.~~ Apparatus according to claim ~~29~~, in which the perimeter limit of successive-area scanning is a circle of constant radius, whereby to prepare a circular corneal recess of constant depth for reception of a corneal transplant.

20 8
~~41.~~ Apparatus according to claim ~~29~~, in which said microprocessor means includes means for coordinated control of said scan-deflection means in one or more adjacent concentrically related annular zonal areas and in the central circular zonal area adjacent and within the innermost annular zonal area, said innermost annular area having an outer circular perimeter which is of incrementally larger radius

than that of its inner circular perimeter, and the radius of said inner circular perimeter being substantially the radius of the perimeter of said circular zonal area, said microprocessor means further including means for successive-area scanning of said innermost annular zonal area in a pattern of outer-perimeter radius variation at constant inner-perimeter radius, and for successive-area scanning of said central circular zonal area in a pattern of outer-perimeter radius variation; whereby to prepare a Fresnel-characterized myopia-correcting anterior-surface profile.

~~42.~~ 21 Apparatus according to claim ~~29~~ 8, in which said microprocessor means includes means for coordinated control of said scan-deflection means in one or more adjacent concentrically related annular zonal areas and in the central circular zonal area adjacent and within the innermost annular zonal area, said innermost annular area having an outer circular perimeter which is of incrementally larger radius than that of its inner circular perimeter, and the radius of said inner circular perimeter being substantially the radius of the perimeter of said circular zonal area, said microprocessor means further including means for successive-area scanning of said innermost annular zonal area in a pattern of inner-perimeter radius variation at constant outer-perimeter radius, and for successive-area scanning of said central circular zonal area in a pattern of annular areas wherein the outer-perimeter radius is constant and the inner radius varies; whereby to prepare a Fresnel-characterized hyperopia-correcting anterior-surface profile.

D' cont'd

~~43.~~ 22 Apparatus according to claim ~~29~~ 8, in which said microprocessor means includes means for coordinated control of said scan-deflection means in each of a plurality of concentrically related contiguous annular zonal areas, the innermost of which has an inner perimeter of substantially zero inner radius, each annular zonal area having an outer circular perimeter which is of incrementally larger radius than that of its inner circular perimeter, said microprocessor means further including means for successive area scanning

of each annular zonal area in a pattern of outer-perimeter radius variation at constant inner-perimeter radius; whereby to prepare a Fresnel-characterized myopia-correcting anterior-surface profile.

~~44.~~ 23 Apparatus according to claim ~~29,~~ 8 in which said microprocessor means includes means for coordinated control of said scan-deflection means in each of a plurality of concentrically related contiguous annular zonal areas, the innermost of which has an inner perimeter of substantially zero inner radius, each annular zonal area having an outer circular perimeter which is of incrementally larger radius than that of its inner circular perimeter, said microprocessor means further including means for successive area scanning of each annular zonal area in a pattern of inner-perimeter radius variation at constant outer-perimeter radius; whereby to prepare a Fresnel-characterized hyperopia-correcting anterior-surface profile.

D1 Cont'd.

~~45.~~ 24 Apparatus for performing ophthalmological surgery by selective ablation of the anterior surface of the cornea with penetration into the stroma to achieve a volumetric removal of corneal tissue, said apparatus comprising laser means having a chassis and producing an output beam in the ultraviolet portion of the electromagnetic spectrum and characterized by a relatively small spot at cornea impingement, said laser including means for adjusting beam-exposure flux to a level at which resultant corneal-tissue ablation per unit time is to an ascertained elemental depth which is but a fraction of desired maximum depth of ablation into the stroma region of the cornea, scan-deflection means positioned for deflection of said beam in a limited field about a central axis, means for steadying the cornea with respect to said chassis and with the central area of the cornea centered on the central axis of scan deflection of said beam, said scan-deflection means having two coordinates of deflection for area coverage within the perimeter of said central area, and means including a microprocessor for coordinating the operation of said scan-deflection means in a controlled program of concentric-circle coverage to establish greatest cumulative

beam exposure of a least-radius circular area and least cumulative beam exposure of a greatest-radius circular area, whereby to effect a myopia-correcting curvature change in the external surface of the cornea.

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~~46.~~ Apparatus for performing ophthalmological surgery by selective ablation of the anterior surface of the cornea with penetration into the stroma to achieve a volumetric removal of corneal tissue, said apparatus comprising laser means having a chassis and producing an output beam in the ultraviolet portion of the electromagnetic spectrum and characterized by a relatively small spot at cornea impingement, said laser including means for adjusting beam-exposure flux to a level at which resultant corneal-tissue ablation per unit time is to an ascertained elemental depth which is but a fraction of desired maximum depth of ablation into the stroma region of the cornea, scan-deflection means positioned for deflection of said beam in a limited field about a central axis, means for steadying the cornea with respect to said chassis and with the central area of the cornea centered on the central axis of scan deflection of said beam, said scan-deflection means having two coordinates of deflection for area coverage within the perimeter of said central area, and means including a microprocessor for coordinating the operation of said scan-deflection means in a controlled program of concentric-circle coverage to establish greatest cumulative beam exposure of a greatest-radius circular area and least cumulative beam exposure of a least-radius circular area, whereby to effect a hyperopia-correcting curvature change in the external surface of the cornea.

D' Contd.

26

~~47.~~ Apparatus for performing ophthalmological surgery by selective ablation of the anterior surface of the cornea with penetration into the stroma to achieve a volumetric removal of corneal tissue, said apparatus comprising laser means producing an output beam in the ultraviolet portion of the electromagnetic spectrum and characterized by a spot which at cornea impingement is small in relation to the cornea to be operated upon, said laser means including means

for adjusting beam-exposure flux to a level at which resultant corneal-tissue ablation per unit time is to an ascertained elemental depth which is but a fraction of a predetermined maximum depth of ablation into the stroma, scan-deflection means positioned for deflection of said beam in a limited field about a central axis, said scan-deflection means having two coordinates of deflection for area coverage within the perimeter of said limited field, and control means with coordinating control connections to said scan-deflection means and to said laser for varying the perimeter of successive area scans within said field wherein said area scans are symmetrical about the central axis, whereby said scan-deflection means may perform one area scan within one perimeter limit before performing another area scan within another perimeter limit, whereby to effect a controlled sculpturing action upon the cornea to alter the optical properties thereof.

D Cont'd.

27

48. Apparatus for performing ophthalmological surgery by selective ablation of the anterior surface of the cornea with penetration into the stroma to achieve a volumetric removal of corneal tissue, said apparatus comprising laser means producing an output beam in the ultraviolet portion of the electromagnetic spectrum and characterized by a spot which at cornea impingement is small in relation to the cornea to be operated upon, said laser means including means for adjusting beam-exposure flux to a level at which resultant corneal-tissue ablation per unit time is to an ascertained elemental depth which is but a fraction of a predetermined maximum depth of ablation into the stroma, scan-deflection means positioned for deflection of said beam in a limited circular field of maximum radius about a central axis, said scan-deflection means having two coordinates of deflection for area coverage within the circumference of said circular field, and control means with coordinating control connections to said scan-deflection means and to said laser for varying the radius from one to another area scan within said circular field, whereby successive area scans may be circular and at different radii about the

central axis, whereby to effect a controlled sculpturing action upon the cornea to effect a myopia-reducing alteration of the optical properties thereof.

28
~~49.~~ Apparatus for performing ophthalmological surgery by selective ablation of the anterior surface of the cornea with penetration into the stroma to achieve a volumetric removal of corneal tissue, said apparatus comprising laser means producing an output beam in the ultraviolet portion of the electromagnetic spectrum and characterized by a spot which at cornea impingement is small in relation to the cornea to be operated upon, said laser means including means for adjusting beam-exposure flux to a level at which resultant corneal-tissue ablation per unit time is to an ascertained elemental depth which is but a fraction of a predetermined maximum depth of ablation into the stroma, scan-deflection means positioned for deflection of said beam in a limited circular field of maximum radius about a central axis, said scan-deflection means having two coordinates of deflection for area coverage within the circumference of said circular field, and control means with control connections to said scan-deflection means and to said laser for varying between a minimum and substantially said maximum the inner radius of an annular area having its outer radius at said maximum, said inner radius variation being from one to another annular-area scan, whereby successive area scans may be annular and with different inner radii about the central axis, whereby to effect a controlled sculpturing action upon the cornea to effect a hyperopia-reducing alteration of the optical properties thereof.

D Cont'd.

29
~~50.~~ Apparatus for performing ophthalmological surgery by selective ablation of the anterior surface of the cornea with penetration into the stroma to achieve a volumetric removal of corneal tissue, said apparatus comprising laser means producing an output beam in the ultraviolet portion of the electromagnetic spectrum and characterized by a spot which at cornea impingement is small in relation to the cornea to be operated upon, said laser means including means for

adjusting beam-exposure flux to a level at which resultant corneal-tissue ablation per unit time is to an ascertained elemental depth which is but a fraction of a predetermined maximum depth of ablation into the stroma, scan-deflection means positioned for deflection of said beam in a limited field about a central axis, said scan-deflection means having two coordinates of deflection for area coverage within the perimeter of said limited field, and control means coordinating control connections to said scan-deflection means and to said laser for determining a succession of area scans of said field, whereby said scan-deflection means may perform one area scan within said perimeter limit before performing another area scan within said perimeter limit, whereby to effect an ablative excavation of predetermined substantially uniform depth into the stroma.

D cont'd.

30
~~51.~~ Apparatus for performing ophthalmological surgery by selective ablation of the anterior surface of the cornea with varied penetration up to a predetermined maximum penetration into the stroma to achieve an anterior-curvature change by volumetric removal of tissue within the optically functioning area of the cornea, said apparatus comprising: a laser producing a pulsed laser beam in the ultraviolet region of the electromagnetic spectrum; means for shaping, focusing and directing the beam toward the cornea with an intensity to produce tissue penetration to a depth per pulsed exposure which is but a fraction of said predetermined maximum; said means including means for selectively (a) determining and controlling one circular area of exposure to the extent of at least said fractional depth and (b) determining and controlling a different circular area of exposure to the extent of at least said fractional depth, each of said circular areas being within the optically functioning area of the cornea and concentrically disposed with respect to the optical axis of the cornea; whereby the cumulative penetration of the cornea for both said areas of exposure can effect a myopia-reducing corrective change in the curvature of the cornea.

52. Apparatus for performing ophthalmological surgery by selective ablation of the anterior surface of the cornea with varied penetration up to a predetermined maximum penetration into the stroma to achieve an anterior-curvature change by volumetric removal of tissue within the optically functioning area of the cornea, said apparatus comprising: a laser producing a laser beam in the ultraviolet region of the electromagnetic spectrum; means for shaping, focusing and directing the beam toward the cornea with an intensity to produce tissue penetration to a depth per unit time exposure which is but a fraction of said predetermined maximum; said means including means for selectively (a) determining and controlling one circular area of exposure to the extent of at least said fractional depth and (b) determining and controlling a different circular area of exposure to the extent of at least said fractional depth, each of said circular areas being within the optically functioning area of the cornea and concentrically disposed with respect to the optical axis of the cornea; whereby the cumulative penetration of the cornea for both said areas of exposure can effect a myopia-reducing corrective change in the curvature of the cornea.

D' Cont'd.

31
~~53~~. Apparatus for performing ophthalmological surgery by selective ablation of the anterior surface of the cornea with varied penetration up to a predetermined maximum penetration into the stroma to achieve an anterior-curvature change by volumetric removal of tissue within the optically functioning area of the cornea, said apparatus comprising: a laser producing a pulsed laser beam in the ultraviolet region of the electromagnetic spectrum; means for shaping, focusing and directing the beam toward the cornea with an intensity to produce tissue penetration to a depth per pulsed exposure which is but a fraction of said predetermined maximum; said means including means for selectively (a) determining and controlling one circularly annular area of exposure to the extent of at least said fractional depth and (b) determining and controlling a different circularly annular area of exposure to the extent of at least said fractional depth, each of said circularly annular areas being within the optically functioning circular area of the cornea and concentrically disposed with respect to the optical axis of the cornea;

said areas having overlapping relation at least to the outer diameter of the optically functioning area, and one of said annular areas having a lesser inner diameter than the other of said annular areas; whereby the cumulative penetration of the cornea for both said annular areas of exposure can effect a hyperopia-reducing corrective change in the curvature of the cornea.

33
~~54.~~ Apparatus for performing ophthalmological surgery by selective ablation of the anterior surface of the cornea with varied penetration up to a predetermined maximum penetration into the stroma to achieve an anterior-curvature change by volumetric removal of tissue within the optically functioning area of the cornea, said apparatus comprising: a laser producing a laser beam in the ultraviolet region of the electromagnetic specturm; means for shaping, focusing and directing the beam toward the cornea with an intensity to produce tissue penetration to a depth per unit time exposure which is but a fraction of said predetermined maximum; said means including means for selectively (a) determining and controlling one circularly annular area of exposure to the extent of at least said fractional depth and (b) determining and controlling a different circularly annular area of exposure to the extent of at least said fractional depth, each of said circularly annular areas being within the optically functioning circular area of the cornea and concentrically disposed with respect to the optical axis of the cornea, said areas having overlapping relation at least to the outer diameter of the optically functioning area, and one of said annular areas having a lesser inner diameter than the other of said annular areas; whereby the cumulative penetration of the cornea for both said areas can effect a hyperopia-reducing corrective change in the curvature of the cornea.

D1 cont'd.

34
~~55.~~ Apparatus for performing ophthalmological surgery by selective ablation of the anterior surface of the cornea with varied penetration up to a predetermined maximum penetration into the stroma to achieve an anterior-curvature change by volumetric removal of tissue within the optically functioning area of the cornea, said apparatus comprising:

a laser producing a pulsed laser beam in the ultraviolet region of the electromagnetic spectrum; means for shaping, focusing and directing the beam toward the cornea with an intensity to produce tissue penetration to a depth per pulsed exposure which is but a fraction of said predetermined maximum; said means including control means for selectively determining and controlling one corneal area of laser-beam exposure to the extent of at least said fractional depth (a) in one or more adjacent concentrically related annular zones within the optically functioning area of the cornea and (b) in the central circular zonal area adjacent and within the innermost annular zonal area, said innermost annular area having an outer circular perimeter which is of incrementally larger radius than that of its inner circular perimeter, and the radius of said inner circular perimeter being substantially the radius of the perimeter of said circular zonal area; said control means further selectively determining and controlling other corneal areas of laser-beam exposure to the extent of at least said fractional depth wherein for the innermost annular zonal area the outer-perimeter radius varies and the inner-perimeter radius is constant, and wherein for the central circular zonal area the outer-perimeter radius varies; whereby the cumulative corneal penetration of the cornea for both said corneal-area exposures can effect a Fresnel-characterized myopia-reducing corrective change in the curvature of the cornea.

D' cont'd.

35

58. Apparatus for performing ophthalmological surgery by selective ablation of the anterior surface of the cornea with varied penetration up to a predetermined maximum penetration into the stroma to achieve an anterior-curvature change by volumetric removal of tissue within the optically functioning area of the cornea, said apparatus comprising: a laser producing a laser beam in the ultraviolet region of the electromagnetic spectrum; means for shaping, focusing and directing the beam toward the cornea with an intensity to produce tissue penetration to a depth per unit time

exposure which is but a fraction of said predetermined maximum; said means including control means for selectively determining and controlling one corneal area of laser-beam exposure to the extent of at least said fractional depth (a) in one or more adjacent concentrically related annular zones within the optically functioning area of the cornea and (b) in the central circular zonal area adjacent and within the innermost annular zonal area, said innermost annular area having an outer circular perimeter which is of incrementally larger radius than that of its inner circular perimeter, and the radius of said inner circular perimeter being substantially the radius of the perimeter of said circular zonal area; said control means further selectively determining and controlling other corneal areas of laser-beam exposure to the extent of at least said fractional depth wherein for the innermost annular zonal area the outer-perimeter radius varies and the inner-perimeter radius is constant, and wherein for the central circular zonal area the outer-perimeter radius varies; whereby the cumulative corneal penetration of the cornea for both said corneal-area exposures can effect a Fresnel-characterized myopia-reducing corrective change in the curvature of the cornea.

D/ Cont'd.

36
57. Apparatus for performing ophthalmological surgery by selective ablation of the anterior surface of the cornea with varied penetration up to a predetermined maximum penetration into the stroma to achieve an anterior-curvature change by volumetric removal of tissue within the optically functioning area of the cornea, said apparatus comprising: a laser producing a pulsed laser beam in the ultraviolet region of the electromagnetic spectrum; means for shaping, focusing and directing the beam toward the cornea with an intensity to produce tissue penetration to a depth per pulsed exposure which is but a fraction of said predetermined maximum; said means including control means for selectively determining and controlling one corneal area of laser-beam exposure to the extent of at least said fractional depth (a) in one or more adjacent concentrically related annular zones within the optically functioning area of the cornea and (b) in the central circular zonal area adjacent and within the innermost annular zonal area, said innermost annular area having an outer circular perimeter which is of incrementally larger radius than that of

its inner circular perimeter, and the radius of said inner circular perimeter being substantially the radius of the perimeter of said circular zonal area; said control means further selectively determining and controlling other corneal areas of laser-beam exposure to the extent of at least said fractional depth wherein for the innermost annular zonal area the outer-perimeter radius is constant and the inner-perimeter radius varies, and wherein for the central circular zonal area the outer-perimeter radius is constant and the inner-perimeter radius varies; whereby the cumulative corneal penetration of the cornea for both said cornea-area exposures can effect a Fresnel-characterized hyperopia-reducing corrective change in the curvature of the cornea.

D1 cont'd.

~~38.~~ 37. Apparatus for performing ophthalmological surgery by selective ablation of the anterior surface of the cornea with varied penetration up to a predetermined maximum penetration into the stroma to achieve an anterior-curvature change by volumetric removal of tissue within the optically functioning area of the cornea, said apparatus comprising: a laser producing a laser beam in the ultraviolet region of the electromagnetic spectrum; means for shaping, focusing and directing the beam toward the cornea with an intensity to produce tissue penetration to a depth per unit time exposure which is but a fraction of said predetermined maximum; said means including control means for selectively determining and controlling one corneal area of laser-beam exposure to the extent of at least said fractional depth (a) in one or more adjacent concentrically related annular zones within the optically functioning area of the cornea and (b) in the central circular zonal area adjacent and within the innermost annular zonal area, said innermost annular area having an outer circular perimeter which is of incrementally larger radius than that of its inner circular perimeter, and the radius of said inner circular perimeter being substantially the radius of the perimeter of said circular zonal area; said control means further selectively determining and controlling other corneal areas of laser-beam exposure to the extent of at least said fractional depth wherein for the innermost annular zonal area the outer-perimeter radius is constant and the inner-perimeter radius

varies, and wherein for the central circular zonal area the outer-perimeter radius is constant and the inner-perimeter radius varies; whereby the cumulative corneal penetration of the cornea for both said cornea-area exposures can effect a Fresnel-characterized hyperopia-reducing corrective change in the curvature of the cornea.

~~59.~~ 38 Apparatus for performing ophthalmological surgery by selective ablation of the anterior surface of the cornea with varied penetration up to a predetermined maximum penetration into the stroma to achieve an anterior-curvature change by volumetric removal of tissue within the optically functioning area of the cornea, said apparatus comprising: a laser producing a pulsed laser beam in the ultraviolet region of the electromagnetic spectrum; means for shaping, focusing and directing the beam toward the cornea with an intensity to produce tissue penetration to a depth per pulsed exposure which is but a fraction of said predetermined maximum; said means including means for selectively determining and controlling a circular area of exposure to the extent of at least said fractional depth and thereafter determining and controlling one or more further like and coaxially related circular areas of exposure to the extent of at least said fractional depth, each of said areas including the optically functioning area of the cornea; whereby the cumulative penetration of the cornea for said corneal-area exposures will prepare a circular corneal recess of constant depth for reception of a corneal transplant.

D Cont'd.

~~60.~~ 39 Apparatus for performing ophthalmological surgery by selective ablation of the anterior surface of the cornea with varied penetration up to a predetermined maximum penetration into the stroma to achieve an anterior-curvature change by volumetric removal of tissue within the optically functioning area of the cornea, said apparatus comprising: a laser producing a laser beam in the ultraviolet region of the electromagnetic spectrum; means for shaping, focusing and directing the beam toward the cornea with an intensity to produce tissue penetration to a depth per unit time exposure which is but a fraction of said predetermined maximum; said

means including means for selectively determining and controlling a circular area of exposure to the extent of at least said fractional depth and thereafter determining and controlling one or more further like and coaxially related circular areas of exposure to the extent of at least said fractional depth, each of said areas including the optically functioning area of the cornea; whereby the cumulative penetration of the cornea for said corneal-area exposures will prepare a circular corneal recess of constant depth for reception of a corneal transplant.

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~~61.~~ Apparatus for performing ophthalmological surgery to reduce an ascertained astigmatic condition by selective ablation of the anterior surface of the cornea with varied penetration up to a predetermined maximum penetration into the stroma to achieve an anterior-curvature change by volumetric removal of tissue within the optically functioning area of the cornea, said apparatus comprising: a laser producing a pulsed laser beam in the ultraviolet region of the electromagnetic spectrum; means for shaping, focusing and directing the beam toward the cornea with an intensity to produce tissue penetration to a depth per pulsed exposure which is but a fraction of said predetermined maximum; said means including means for selectively (a) determining and controlling one rectangular area of exposure to the extent of at least said fractional depth and (b) determining and controlling a different rectangular area of exposure to the extent of at least said fractional depth, said rectangular areas being of varying width and symmetrical about a central axis through the optical axis of the cornea and oriented in accordance with the ascertained astigmatic condition; whereby the cumulative penetration of the cornea for both said areas of exposure can effect an astigmatism-reducing corrective change in the curvature of the cornea.

D' Cont'd.